

## ON PHYSICAL LINES OF FORCE IN ELECTRICAL THEORY.

BY FERNANDO SANFORD.

IN most of the discussions of electrical theory since the publication of Maxwell's great treatise the physical lines of force assumed by Faraday have played an important part. There have been various concepts as to the character of these lines of force, but apparently all who have used them have agreed in assigning to them the property of contraction lengthwise combined with another property equivalent to a repulsion at right angles to their length. Faraday apparently thought of them as elastic cords attached at their ends to unlike charges of electricity and tending to shorten and become thicker like muscle fibers. Maxwell apparently conceived of them as lines of polarized molecules imbedded in a dielectric medium, something after the order of the hypothetical Grotthus chain in electrolysis. Other writers have assumed the ether to consist of cells or molecules of positive and negative electricity and to be sheared by electric stresses so that positive electricity appears at one boundary of the stress and negative electricity at the other, while J. J. Thomson has conceived of them as some sort of vortex filaments running through, but differentiated from, the rest of the ether and terminating in a positive atom at one end and a negative atom or electron (corpuscle) at the other.

It has seemed to the present writer that the most logical and complete development of the idea of physical lines or tubes of force is to be found in the writings of Professor J. J. Thomson, and it is the purpose of the present paper to discuss some of Thomson's ideas and to inquire into the validity of some of the hypotheses which he has built upon them.

Thomson has realized clearly that physical lines or tubes of force must be finite in number. He says (*Experimental Researches*, 3): "In the mathematical theory of electricity there is nothing to indi-

cate that there is any limit to the extent to which a field of electric force can be subdivided up into tubes of continually diminishing strength; the case is however different if we regard these tubes of force as being no longer merely a form of mathematical expression, but as real physical quantities having definite sizes and shapes. If we take this view, we naturally regard the tubes as being all of the same strength, and we shall see reasons for believing that this strength is such that when they terminate on a conductor there is at the end of the tube a charge of negative electricity equal to that which in the theory of electrolysis we associate with an atom of a monovalent element such as chlorine.

"This strength of the unit tubes is adopted because the phenomena of electrolysis show that it is a natural unit, and that fractional parts of this unit do not exist, at any rate in electricity that has passed through an electrolyte."

That Thomson still holds to this definition of a unit Faraday tube may be seen from his discussion of the constitution of the atom in his recent work on "Electricity and Matter." He says (Elec. and Mat., p. 133): "Now, on the electrical view of chemical combination, a univalent atom has one unit charge, if we take as our unit of charge the charge on the corpuscle; the atom is therefore the beginning or end of one unit Faraday tube: the beginning if the charge on the atom is positive, the end if the charge is negative. A divalent atom has two units of charge and therefore it is the origin or termination of two unit Faraday tubes. Thus, if we interpret the 'bond' of the chemist as indicating a unit Faraday tube, connecting charged atoms in the molecule, the structural formulæ of the chemist can be at once translated into the electrical theory."

This concept of the tube of force would seem to make the total number of Faraday tubes in the physical universe a constant, *i. e.*, one for each pair of unit positive and negative charges, and Thomson has recognized this necessity. He says (Ex. Res., 4): "These tubes also resemble the molecules of a gas in another respect, as we regard them as incapable of destruction or creation."

This would seem to mean that each unit charge of negative electricity, *i. e.*, each electron (corpuscle) in the physical universe is indissolubly connected by a unit tube of force to its own particular

positive atom, and that these unit positive and negative charges cannot change partners because to do so would oblige them to part with their own tube of force, or atomic bond, and take on a new one, and this would involve at least the temporary destruction of both tubes of force.

This plain deduction from all the possible definitions of unit physical tubes of force seems to have been overlooked by physicists who have adopted the theory, and it is inconsistent with our understanding of many of the commonest chemical phenomena. All chemical reactions are apparently dependent upon the ability of the electropositive and electronegative constituents of the reacting molecules to exchange partners.

Again, since an electron or a monovalent atom can have only one tube of force ending or beginning upon it, it can be acted upon by no other electric force whatever. An electron in any electric field is acted upon by only its own tube of force and is impelled only toward its own positive atom, and no electric force whatever can cause it to deviate from the direction of its own tube of force.

This would make it impossible for tubes of force to stretch across from one charged conductor to another, since there would be nothing at either end to hold the unit charges to their respective conductors, hence no tube of force could ever be of more than molecular dimensions.

It also follows from this assumption of unit tubes and the accepted electrical theory which goes with it that an electron can have no magnetic field of its own, since in the theory the magnetic field is due to the motion of tubes of force in a direction at right angles to their length, and an electron can have no tubes of force projecting at right angles to its direction of motion. This would seem to make necessary some other interpretation of Thomson's calculation of the electric mass of the electrons thrown off by radium in Kauffmann's experiments (*Phil. Mag.*, 8, 331; *Elec. and Mat.*, Chap. II.). Here Thomson has assumed a great number of Faraday tubes radiating from an electron as from a charged sphere, and by their motion at right angles to their length setting up an electromagnetic field. If it can be shown, as seems to be the case, that a single electron moving through the ether may have an electromagnetic

field, and hence an "electrical mass," it would seem that the idea of the unit tube of force must be abandoned or that the magnetic field must be explained by something other than the transverse motion of these tubes.

But this is not the only place where the Faraday tubes seem inadequate to explain the phenomena for which they were invented. In the attempt to explain the electromagnetic field of a current by the transverse motion of Faraday tubes it seems necessary to assume that positive electricity is leaving one plate of the battery and negative electricity the other (Ex. Res., 40; Elec. and Mat., 17) and that these opposite charges meet in the conductor where the Faraday tubes shrink to molecular dimensions. This means that one half of any electric current consists of positive charges traveling in one direction while the other half consists of negative charges traveling in the opposite direction to meet them. In other words, in any closed electric circuit one half of the conductor contains positive atoms in motion and the other half contains negative electrons moving to meet them. This seems contrary to experience, since there is no evidence that the positive atoms of a solid conductor move with the current.

On the other hand, there is strong evidence that such motion does not take place. For consider a battery composed of a zinc and an iron plate joined by a copper wire. According to the theory, a tube of force must start from a positive iron atom and a negative zinc electron and must run along between the two halves of the conducting wire carrying the iron atom at one end and the electron at the other until these meet to form a neutral iron atom in the copper wire. As we have already seen, the Faraday tube cannot release one positive atom and seize another, since in so doing it would have to exist for a finite time with a unit charge at only one end, which is contrary to the definition of all physical lines or tubes of force as well as contradictory to the third law of motion.

A similar difficulty is met with in explaining the induction of one current by another. Here the Faraday tube starting from the positive and negative ends of the primary circuit must break when it reaches the secondary circuit (Ex. Res., 41), and by taking up two unit charges from a molecule in this circuit must divide into two

Faraday tubes, destroying as it does so the Faraday tube which originally held together the positive and negative parts of the atom which it separates. When it leaves these positive and negative parts of the atom at the other side of the secondary circuit, it must again break away from both and its free ends must unite, while a new Faraday tube comes into existence between the charged parts of the atom which now meet again in the secondary circuit.

Still another difficulty is met with in the use of the concept of Faraday tubes in the Electromagnetic Theory of Light. Here the source of light is supposed to emit Faraday tubes which move through the ether transversely to their length (Ex. Res., 42). From this point of view, a beam of plane polarized light consists of a great number of straight parallel Faraday tubes traveling through the ether at right angles to their length and with the velocity of light.

Since a beam of light has definite boundaries, these Faraday tubes must be of finite length certainly not greater than the transverse diameter of the beam, and each must carry a unit positive charge at one end and a unit negative charge at the other, *i. e.*, each Faraday tube must have a positive atom at one end and an electron at the other. This, of course, is entirely contrary to experience. Furthermore, Thomson's calculation of the electrical mass of a positive atom or electron having unit charge leads to the conclusion that this electrical mass would be infinite for charges moving with the velocity of light. Hence, from Thomson's assumptions a beam of plane polarized light consists of a very great number of Faraday tubes, each with an infinite mass at each end, moving with the velocity of light.

The above examples are cited to show the inadequacy of physical lines or tubes of force for explaining the ordinary phenomena of electricity. On the other hand, a mere mathematical line of force does not explain anything. It would seem that as long as electrical phenomena are explained by attractions between positive and negative charges either the notion of action at a distance must be revived or some kind of a physical line of force must be assumed as attached at its ends to these charges and by its contraction pulling them together.

If, on the other hand, electric phenomena may be explained by repulsions due to a pressure exerted by the electrons upon the surrounding ether, no physical lines of force are necessary, and no properties but those required by the elastic solid theory of light need be attributed to the ether.

STANFORD UNIVERSITY,  
December, 1907.